Adaptive time-frequency analysis of signals in AFM

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The probe-sample interactions during the AFM experiments represent a case of multi-frequency behaviour, since they are characterized by the simultaneous excitation of several modes and/or cantilever harmonics. Analysis of the data obtained as a result of interaction between the probe and the sample is of a particular interest not only from a practical point of view, i.e. obtaining information about the surface of the sample, but also this is an interesting methodological task, since the instantaneous processes resulting from the interaction of the probe with the sample surface carry a huge amount of information. To obtain it, it is necessary to provide an analysis method that is capable of characterizing all the excited cantilever frequencies simultaneously and without averaging, in contrast to the cyclic averaging used in standard methods. In other words, it is necessary to obtain the complete spectral response of the cantilever interacting with the sample, i.e. information about the dynamics of cantilever behaviour in time.

Traditionally, AFM signal analysis is performed by using Fourier transform (FT), which provides high accuracy and analysis speed. However, signal transformation from time to frequency domain by means of FT makes difficult or impossible the process of attribution of the particular parts of the spectrum to their time of appearance. In addition, the Fourier spectrum shows the averaged spectrum corresponding to the state of the system during a certain acquisition time. Thus, the spectral analysis provided by the FT gives a correct interpretation only in cases of stationary signals. The data of AFM experiments contain a lot of non-stationary or transient characteristics, and these characteristics are important parts of the signal. To analyze this type of signals, a method that allows obtaining information about instantaneous changes in rapidly varying signal parameters, as well as performing simultaneous analysis of all cantilever frequencies in the bandwidth of the detection system is required. As such an analysis method, the wavelet transform (WT) method can be used.

Wavelet transform is a powerful and well-developed mathematical tool that combines time and frequency domain. Until now, the most important application of wavelet transform in AFM was its use to reduce noise or extract data from an image of a surface topography. However, the use of WT in AFM as a tip-sample interaction signal analysis technique can give information about the temporal development of the spectral components of the cantilever signal. In other words, the WT gives a representation of the time evolution of the amplitude, frequency, and phase shift of each of the considered modes and/or cantilever harmonics. Such an advantage of the WT can be used to analyze the signals of any AFM experiments, but it is especially important in analyzing the signals of a multifrequency AFM experiments, since the correlation with time of individual spectral components can provide new information on the behaviour of the cantilever, and thus, on the properties of the surface [1-4]. Worth to notice, the basis of WT is called mother wavelet and it is not unified, but should be chosen according to the characteristics of the study signal. There are a number of mother wavelets that can be used for analysis and the choice of the mother wavelet should be done in accordance with the task that needs to be solved in the particular case. The aim of the present work is to show the possibilities of wavelet transform application in analyzing the signals of a multifrequency AFM experiments.

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